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SUBJECT—

TITLE

VARIANCE OF GROWTH RATE

FOR INDEX TREES

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Portland, Oregon
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For a number of years, the influence of climatic and environmental factors on the general growth rate of ponderosa pines on 320-acre and 640-acre sample plots in the pine region of eastern Oregon and Washington has been judged by a comparison of the growth rate of so-called "index trees," primarily class 3A; but including a few class 2A and 3B trees. Ordinarily a series of 15 or more increment cores has been taken from such trees scattered through the plot and the yearly or decadal growth measured and used as an index to the general growth rate of the plot as a whole.

This practice was adopted on the basis of previous studies[1] which showed that the growth pattern, in terms of percent of change from the general class average, was essentially uniform for all tree classes and secondly that growth changes were largely climatic in origin and affect all trees in a given stand more or less uniformly. Class 3A trees were selected as the "index tree" because they were subject neither to the erratic growth of youth nor to the complacent growth of old age, and yet were strongly growing trees most responsive to growth fluctuations.

To see whether or not these were valid assumptions, a series of increment cores was taken by the writer from 120 index trees scattered along a strip cruise through 8 forties of Goodlow Mountain check section (T. 39 S., R. 13 E., sec. 5) on August 11, 1938. These were taken so as to have 15 trees representing each of the 8 forties.

Measurements of the decadal growth from 1870 to 1938 and annual growth during 1923 and 1924 were made by Jack Huber in February 1939, and analysis of variance computations were made by R. C. Grant in March 1941. The results of this study brought out some rather thought-provoking conclusions which are presented below.

Analysis of Annual Growth between 1923 and 1924

The first analysis was made of the ratio of 1924 growth ring to 1923 ring. Table 1 shows these ratios for individual trees in each forty and the average ratio for each forty. The general average for all 120 trees showed the 1924 radial growth to be 41% of the 1923 ring. The variation in this ratio between individual trees ranged from 100% (no reduction) to 12% (reduction of 88%); while the average ratio by forties ranged from 48% to 31%. In fact the mean ratio of each group of 15 trees was quite consistent throughout the entire section.

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[1] Keen, F. P. 1936. Climatic Cycles in Eastern Oregon as Indicated by Tree Rings. Monthly Weather Review, Vol. 65, No. 5, May 1937, pp. 185-188 (Figure 2).

Table 1. Ratio of 1924 ring width to 1923 ring width as between 120 "index trees" on eight forties. Goodlow Mt. plot, T. 39 S., R. 15 E., sec. 5

Tree No.	Location by Forties								Total	Mean
	1	2	3	4	5	6	7	8		
	Percent									
1	44	37	32	50	41	35	48	38	325	41
2	51	42	58	30	53	44	52	36	366	46
3	27	34	43	31	65	37	44	50	331	41
4	34	32	23	33	47	28	40	40	277	35
5	28	45	33	49	32	30	26	25	268	33
6	48	38	25	35	58	50	51	44	349	44
7	45	41	55	39	100	67	41	27	415	52
8	48	43	41	19	45	37	32	42	307	38
9	38	46	39	24	35	51	33	12	278	35
10	43	44	77	24	22	23	62	28	323	40
11	48	39	67	35	30	25	45	21	310	39
12	29	40	51	38	42	51	39	13	303	38
13	54	41	59	51	30	51	45	36	367	46
14	38	49	62	30	39	38	41	40	337	42
15	39	51	51	38	60	36	33	18	326	41
Total	614	622	716	526	699	603	632	470	4,882	
Means	41	41	48	35	46	40	42	31		41

The factorial table showing the sources of variation was as follows:

Table 2. Analysis of variance of growth relation between 1924 and 1923 ring

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Total	119	19537.97	164.18	
Between means of forties	7	3100.37	442.91	3.02+
Within forties	112	16437.60	146.76	

Discussion

The total variation in the 1924/1923 growth ratio between the 120 trees sampled is broken into two parts: (1) That between forties and (2) that within forties. That within forties is used as a measure of experimental error. The mean square variation between the means of forties shows an F value of 3.02, which is highly significant. (F=2.84 for 1% point).

An examination of the means by forties in Table 1 shows these to be so similar that one would hardly expect to find any significant differences between them. The fact that a significant difference does exist indicates that the sampling errors were low and that even slight differences, probably of site, in different parts of the section were reflected in average growth rates.

From these computations it is possible to determine the number of increment core samples required to give a reliable determination of the ratio between 1924 and 1923 growth.

Mean ratio for 120 samples (1924/1923)	40.68%
Standard deviation	12.81%
Standard error	1.17% or 2.9% of mean

If maximum errors are exceeded in not more than 5 percent of cases, then the numbers of samples required for a given maximum error are as follows:

Maximum error of 5% of the mean	N = 159 cores
" " " 10% " " "	N = 41 "
" " " 20% " " "	N = 10 "

Thus with 15 increment cores from index trees, the 1924/1923 ring width ratio could be determined on a section with a maximum error of approximately 16% of the mean. This may sound like a large error, but in the present case it would mean that the average reduction of 41 percent in the 1924 ring over the 1923 ring was determined within a maximum error of (16% x 41%) or ± 6.5%. This in fact is a high degree of accuracy for these particular statistics.

On the basis of this test, the conclusion is reached that a 15-increment-core sample from "index trees" on a given plot does give a reliable basis upon which to compare relative growth differences between plots.

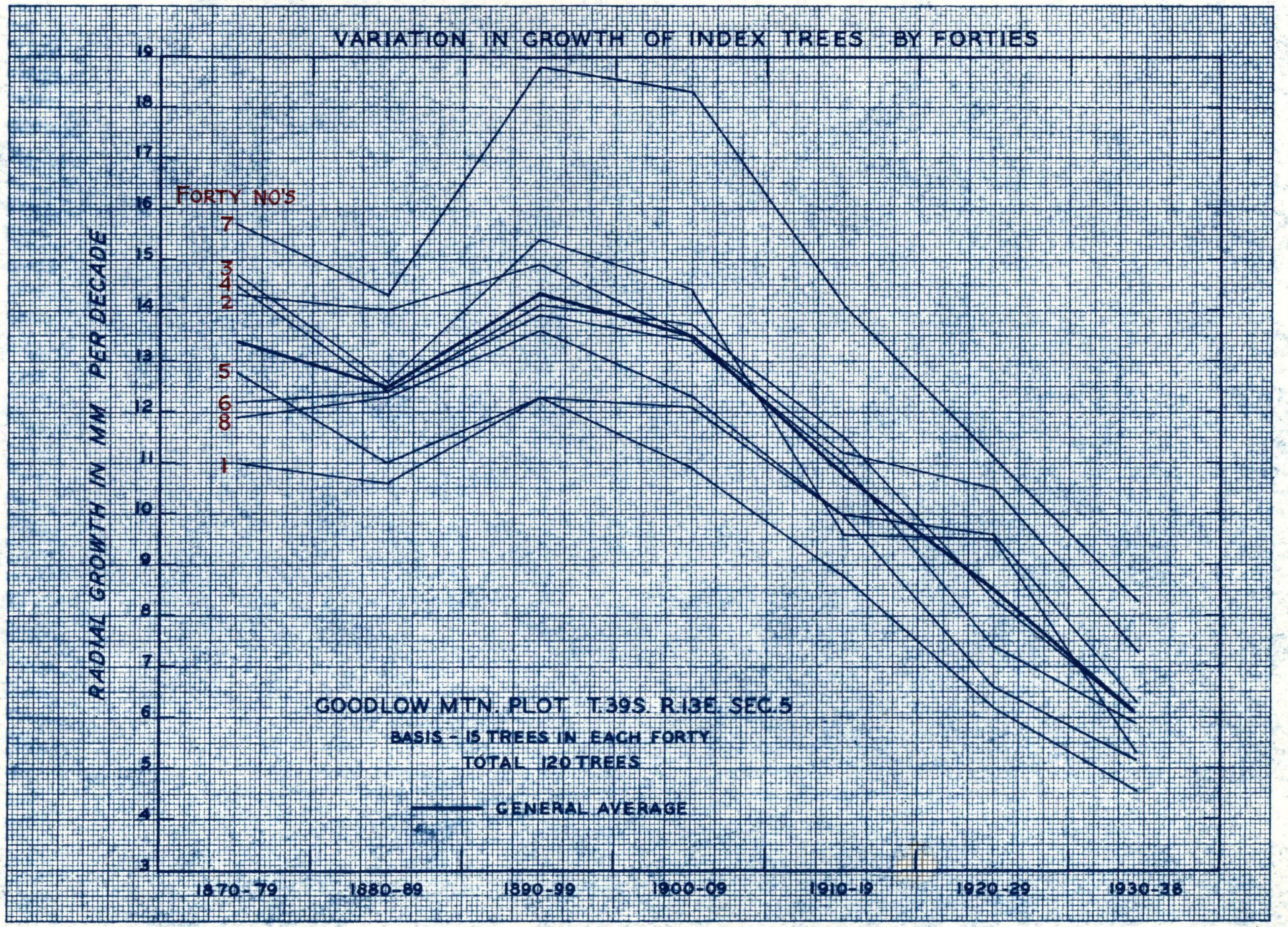
Trend of Growth by Decades

Radial growth measurements were made of the 120 trees by decades starting with 1870, except that the last period was for 9 years from 1930 to 1938 inclusive. The average radial growth by decades and forties is shown in Table 3 and in Graph 1. It will be noted from the graph that the growth pattern was the same through all forties of this section and conforms to the general growth pattern of the region.1/ The pronounced higher growth for forty #7 is explained by an examination of the original data which shows that the index trees from this forty were slightly smaller in diameter (24" against the average of 26") and had a higher proportion of class 2A trees.

1/ Keen, F. P. 1936. Climatic Cycles in Eastern Oregon as Indicated by Tree Rings. Monthly Weather Review, Vol. 65, No. 5, May 1937, pp. 185-188.

Table 3. Average radial growth rate of "index trees" by decades and forties. Goodlow Mt. plot, T. 39 S., R. 15 E., sec. 5

Forty	1870-79	1880-89	1890-99	1900-09	1910-19	1920-29	1930-38
			Millimeters per decade				
1	11.0	10.6	12.3	12.1	10.0	8.6	6.3
2	14.3	14.0	14.9	13.5	11.2	10.5	7.3
3	14.7	12.6	15.4	14.4	9.6	9.5	5.3
4	14.5	12.4	13.9	13.4	11.0	7.4	5.9
5	12.8	11.0	11.8	10.9	8.8	6.2	4.6
6	12.2	12.4	14.1	13.7	11.5	8.3	6.1
7	15.7	14.3	18.8	18.3	14.1	11.1	8.3
8	11.9	12.3	13.6	12.3	10.0	6.6	5.2
General Average	13.4	12.5	14.3	13.5	10.8	8.5	6.1


VARIATION IN GROWTH OF INDEX TREES BY FORTIES
RADIAL GROWTH IN MM PER DECADE
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
FORTY NO'S
7
3
4
2
5
6
8
1
GOODLOW MTN. PLOT T.39S. R.13E. SEC.5
BASIS - 15 TREES IN EACH FORTY
TOTAL 120 TREES
GENERAL AVERAGE
1870-79
1880-89
1890-99
1900-09
1910-19
1920-29
1930-38

Analysis of Growth by Decades and Forties

From inspection of Graph 1 it was obvious that such a wide and consistent variation existed between the early decades, 1870 to 1909, and the more recent period from 1910 to 1938 that there was little point in making an analysis of variance to establish this variation. On the other hand, a significant difference between growth rates in two succeeding decades might not be so obvious without statistical proof.

Therefore an additional analysis was made of the variation in decadal growth rate (in millimeters) between 15 trees on each of 8 forties using two recent periods, the nine-year periods 1920-28 and 1930-38. (Since only 9 years was represented by the growth measurement from 1930-38, the 1920-29 growth measurement was reduced by 1/10 in order to make the two periods comparable.) Table 4 gives the original data which formed the basis of this analysis.

Table 4. Variation between 15 paired observations of 9-year radial growth in eight forties. Growth in millimeters per nine years. I--First growth period 1920-28. II--Second growth period 1930-38

Observations	Growth Periods	Forties								Total	Average
		1	2	3	4	5	6	7	8		
1	I	14.8	13.9	9.5	9.5	5.8	9.0	18.0	7.2	87.7	10.9
	II	12.0	10.5	7.0	6.5	6.5	8.5	10.5	6.5	68.0	8.5
2	I	7.2	13.5	14.0	7.2	5.4	13.1	8.6	9.9	78.9	9.8
	II	6.0	9.5	6.0	7.0	4.0	13.0	7.0	10.0	62.5	7.8
3	I	11.2	9.9	6.8	6.3	9.9	5.4	11.7	10.4	71.6	9.0
	II	9.0	6.0	4.5	9.0	7.0	5.0	10.0	8.5	59.0	7.4
4	I	9.5	10.3	6.3	6.3	4.1	9.0	12.2	5.0	62.7	7.8
	II	10.0	8.0	5.5	4.0	3.0	7.0	9.5	6.5	53.5	6.7
5	I	4.1	14.8	8.6	4.5	5.4	5.0	6.8	8.6	57.8	7.2
	II	2.5	10.5	5.0	5.0	4.5	4.5	6.0	7.0	45.0	5.6
6	I	4.5	9.5	5.8	9.5	4.5	8.6	9.9	5.0	57.3	7.2
	II	4.5	8.0	2.0	9.0	3.0	7.0	11.5	3.0	48.0	6.0
7	I	7.2	11.7	14.8	5.0	6.3	14.8	10.8	3.2	73.8	9.2
	II	5.5	10.0	9.5	4.0	4.0	11.0	6.5	3.0	53.5	6.7
8	I	5.0	8.1	5.8	5.0	6.8	8.1	10.4	8.1	57.3	7.2
	II	2.5	9.0	4.0	4.5	5.0	10.5	9.0	6.5	51.0	6.4
9	I	7.2	3.6	10.8	6.8	4.5	9.9	11.7	5.9	60.4	7.5
	II	4.0	4.5	7.0	5.5	5.5	5.5	10.0	5.0	47.0	5.9
10	I	5.4	6.3	6.8	8.6	5.4	5.9	10.8	4.5	53.7	6.7
	II	5.5	4.5	3.5	7.5	4.0	3.0	13.0	2.5	43.5	5.4
11	I	4.5	3.6	8.1	5.4	5.0	5.9	6.8	2.2	41.5	5.2
	II	4.5	3.0	5.5	5.5	5.5	4.5	8.5	3.0	40.0	5.0
12	I	11.7	6.8	11.3	7.2	5.0	2.7	5.9	2.7	53.3	6.7
	II	8.5	6.5	7.0	6.5	4.5	2.0	6.0	2.0	43.0	5.4
13	I	7.7	7.2	6.3	9.5	3.2	4.1	6.3	8.6	52.9	6.6
	II	8.5	5.5	3.5	7.0	2.5	3.5	4.5	8.0	43.0	5.4
14	I	8.1	13.1	7.6	3.1	7.2	7.7	15.3	4.5	66.6	8.3
	II	4.5	7.5	4.5	3.0	5.0	5.5	7.5	4.0	41.5	5.2
15	I	7.7	9.5	5.8	5.8	5.9	3.2	4.5	4.1	46.5	5.8
	II	6.5	6.5	5.0	5.0	5.5	1.5	5.0	3.0	38.0	4.8
Total		209.8	251.3	207.8	188.7	153.9	204.4	274.2	168.4	1658.5	
Average		7.0	8.4	6.9	6.3	5.1	6.8	9.1	5.6		6.91
										Period I	7.7
										Period II	6.1

Table 5. Analysis of radial growth of "index trees" by two nine-year periods

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Significant
Total	239	2061.96	8.62		
Between means of forties	7	371.25	53.04	7.92	Yes
Between means of periods	1	143.38	143.38	21.43	High
Remainder	231	1547.33	6.69		

This analysis also shows a significant difference between the mean growth rate in various forties. This is probably accounted for by variations in site. The variation between means of periods shows a highly significant difference which was evident from an inspection of Graph 1.

Using the standard deviations shown by this analysis of actual millimeter growth rates for index trees during two nine-year periods, it is possible to compute the number of increment cores necessary to give reliable averages under the conditions found on this sample section.

Mean growth rate for 240 measurements	6.91 mm. per 9 years
Standard deviation " 240 "	2.94 mm.
Standard error " 240 "	.19 mm. or 2.75% of mean

If the maximum error is exceeded in not more than 5 percent of cases, then the numbers of samples required for a given maximum error are as follows:

Maximum error of 5% of mean	N = 290
" " " 10% " "	N = 73
" " " 20% " "	N = 18
" " " 30% " "	N = 8

Comparing these figures with those obtained from the first analysis, it is obvious that nearly twice as many cores are required to obtain an accurate measure of actual millimeter growth rate as are needed to determine the relative growth rate between two periods. The latter purpose has been the principal use served by the taking of 15 increment cores from index trees on regional survey sample plots, and for this purpose the number has been adequate.

Conclusions

The present analysis of growth rates was undertaken to answer certain specific questions, i.e.:

(1) Is there any significant difference between the ratio of growth rate of trees within the same tree class (index trees--Class 3A) in different parts of a 640-acre sample plot (using 40 acres as the smallest subdivision)? This study shows that while slight there are significant differences in various 40-acre tracts within a 640-acre sample plot, probably reflecting slight differences in site, and stand competition. If there had been no differences shown by this study, then we would have been forced to conclude that either the 640 acres were of uniform character, or that the "index trees" were not useful in reflecting differences in site and growth response.

(2) The test showed that the difference in growth by decades was highly significant. This difference is largely the result of climatic effects and in the present case, because the measurements were uncorrected for the normal growth curve of the trees, reflected the decreasing radial growth with an increase in tree age.

(3) How many increment cores are needed from a plot in order to obtain a satisfactory measure of relative growth fluctuations? From this study we find that if we are satisfied with a maximum error of approximately 16 percent of the mean, then 15 increment cores give a satisfactory test of growth reduction in more than 95 percent of cases. If, however, we desire to keep the maximum error under 10% of the mean approximately 40 increment cores per section need to be measured.

To obtain a corresponding accuracy in actual millimeter growth per decade approximately twice as many core measurements are needed.